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LITERATURE SYSTEMATIC REVIEW WITH BIBLIOMETRIC ANALYSIS ON INDUSTRIAL HEATING PROCESSES FEASIBLE TO USE SOLAR THERMAL COLLECTORS IN DAIRY SECTOR

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Abstract. *Bibliometric analysis plays an important role in the evaluation of the scientific production of a particular subject. Its indicators depict the development degree of a knowledge area. It is a fundamental tool for researchers and graduate students. In this sense, the main objective is to identify processes and applications with great potential for using solar thermal heating in the dairy sector in the southern region of Brazil. Articles (reviews, potential analysis and case studies) published in peer-reviewed journals are selected through exploratory and bibliographic research at CAPES Journals Portal and Google Scholar search tool. A systematic review of literature, followed by bibliometric analysis, is carried out based on the following steps: search terms (keywords), read articles (titles, abstracts, keywords, methodology and results) and sort the data (year, country, journal, etc.). This methodology led to a total of 17 articles distributed in 9 journals, with 3 reviews, 11 case studies and 3 potential analyzes. The processes that most appear in the selected articles were pasteurization and drying. Among stationary solar collectors, the cheapest is the flat plate collector, followed by the evacuated tube collector. Both collectors can be used for incident radiation levels in the southern region of Brazil. These collectors are suitable for processes whose water temperature does not exceed 100 ºC, which is the case of pasteurization, drying and washing.*

Keywords: *industrial heating processes, solar thermal heating, solar thermal collectors, dairy industry, systematic review of literature*

1. INTRODUCTION

In recent years, the uses of solar energy have been growing significantly, been used for both fluid heating (thermal conversion) and electricity generation (electric conversion). Due to the versatility, its use is indicated from domestic to large applications, such as industries and solar power plants (photovoltaic or solar thermal).

Thermal conversion is performed through solar thermal collectors, which are special types of heat exchangers (Kalogirou, 2013). There are basically two types of solar thermal collectors: non-concentrators (simpler, for temperatures between 30 and 200 ºC) and concentrators (more sophisticated, for temperatures between 60 and 2,000 ºC). The choice of heat exchanger will depend on the application and the desired fluid temperature.

In the industrial sector about two-thirds of the energy demanded is for fluid heating or heat generation process (Kempener et al., 2015). About 60% of the processes involve fluids at temperatures below 250 ºC (Pietruschka et al., 2012). Thus, the potential of solar thermal energy use in industrial applications (Solar Heat for Industrial Processes, SHIP) is evident. In Germany, for example, Lauterbach et al. (2012) determined a technical potential of 16 TWh per year, approximately. However, in most cases, the limiting factor is the available area for installation (Kempener et al., 2015).

According to Farjana et al. (2018), the countries that stand out in the SHIP use are India, Austria, Germany, the United States, Spain, China, South Africa, Mexico, France and Greece. With regard to these countries, the industrial sectors that stand out are: agriculture, food, beverages and textiles. Similar studies to (Lauterbach et al., 2012) were carried out for India (Suresh and Rao, 2017), China (Jia et al., 2018) and Greece (Karagiorgas et al., 2001). However, there are few studies about SHIP use in Brazilian industries, and none of them are as detailed as the studies cited above.

In this sense, this work aims to a literature systematic review with bibliometric analysis on industrial heating processes feasible to use solar thermal collectors in dairy sector - generally hot water supply to boiler, hot water generator for milk processing and CIP cleaning (Desai et al., 2013). According to Fernández-García et al. (2015), processes such as steam generation, pasteurization and drying require 75% of the energy consumed by this sector. Nevertheless, this sector contributes significantly to the Brazilian industrial Gross National Product, GNP.

2. METHODOLOGY

The literature systematic review was conducted in order to identify current and relevant articles. The CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) Journal Portal was used. This portal is an electronic resource that allows the application of several filters. The sequence of methodology performed, Fig. 1(a), was as follows: (1) search for peer reviewed articles; (2) read the title, abstract and keywords; (3) read the methodology and main results; (4) organize selected articles (in tables); (5) Identify suggestions of future work and subjects with few scientific explorations.

Regarding activity (1), the portal provides two fields for the keywords. In this work the keywords "solar thermal heat" and "dairy milk" were used. The logical operator "AND" has been selected. Thus, we selected only articles that had both sets of keywords. Although the choice of the second keyword seemed redundant, the use of the dairy term only returned results for veterinary medicine. The following filters, Fig. 1(b), were applied in activity (1): peer-reviewed journals, type of publication "scientific article", and year of publication between 2010 and 2019. The last filter was the selection of journals. This search resulted in only 10 articles on the subject of interest, Fig. 1(b).

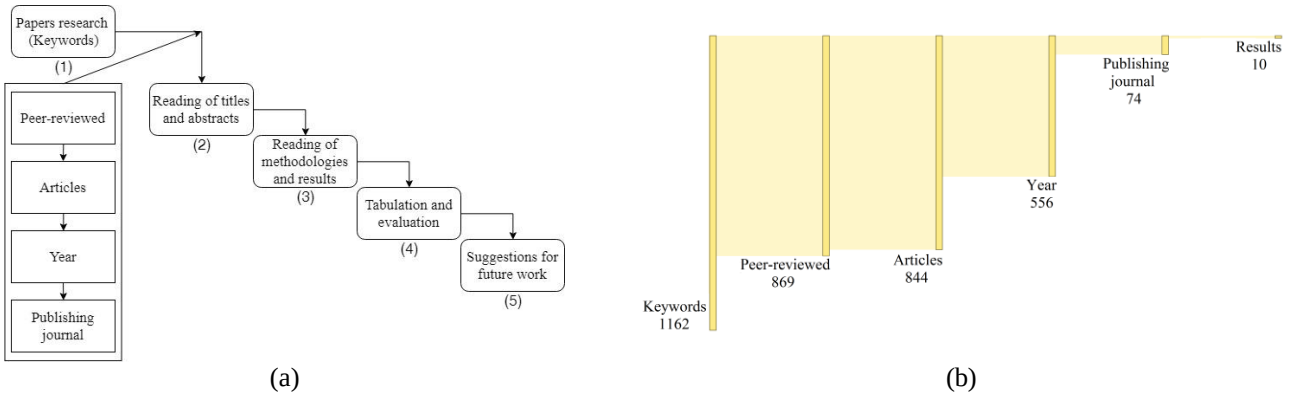

Figure 1. (a) Methodology activities – CAPES Portal. (b) Applied filters.

Thus, it was decided to use another search tool: the electronic portal Google Scholar. Its advantage is to provide results from additional sources not covered by traditional portals, such as Science Direct for example. In this case, only the keyword "solar heat dairy industry" was used, with "articles" selected. The use of the logical “AND” operator and the other keyword returned articles related to veterinary medicine. The year-of-publication filter was also applied (from 2010 to 2019). Only the results presented until the sixth page were analyzed. From the seventh page the results were not relevant or were not associated with the scope of this work. The peer review filter was made article by article. On the journals sites it was possible to find this information and then select the articles.

In activity (2), articles referring to the application of solar thermal energy in the dairy industry were selected. The abstracts were read, and the first selection was made. In a second moment, the methodology and main results of the articles selected, activity (3), were read. Then, the articles were organized in spreadsheets containing the following parameters: year, title, journal, type (review, case study, etc.), solar collector used and the heating process.

3. RESULTS AND DISCUSSION

A total of 1,162 articles were identified in CAPES Journal Portal using only the keywords, Fig. 1(b). The following filters have been applied, one by one. Finally, only the following journals were selected: Applied Energy, Applied Thermal Engineering, Energy, Journal of Cleaner Production, and Renewable and Sustainable Energy; because only these journals appear in Qualis CAPES, Engineering III area. Thus, a total of 10 articles were reached, Fig. 1(b) and Table 1.

Qualis is the set of procedures used by CAPES to stratify the quality of the intellectual production of graduate programs in Brazil. It is designed to meet the specific needs of the evaluation system and is based on the information provided through the Data Collection application. The journals are framed in indices that are indicative of quality - A1, highest, A2, B1, B2, B3, B4, B5; and C with zero weight.

The Google Scholar search returned approximately 31,400 articles using only the keyword and the "articles" option. After applying the filter for the year of publication, there were 17,200 results. Until the sixth page of results, titles and abstracts were read, step (2). Twenty-seven relevant papers were selected, of which 6 had already been selected in the CAPES Portal. Of the remaining 21 articles, only 7 were selected, Tab. 2; since these journals appear in Qualis CAPES Engineering III area.

Thus, the search in the two search tools led to a total of 17 articles. These articles are distributed in 9 journals, Fig. 3, with 70.6% with Qualis A1 journals, 17.3% with Qualis B3 journals, 5.9% in Qualis A2 journals and 5.9% in Qualis B4 journals. The journal with most articles was Energy, with 6 articles, followed by Renewable and Sustainable Energy Reviews and Journal of Cleaner Production, both with 2 articles, Fig. 4. All are classified with Qualis A1. Regarding the type of article, there are 3 reviews, 11 case studies and 3 potential analyzes, Fig. 5.

Table 1. Articles selected from CAPES Portal.

Year	Title/Author	Journal	Type	Collector
2010	Integration of solar thermal for improved energy efficiency in low-temperature-pinch industrial processes (Atkins et al., 2010)	Energy	Case study	Evacuated tube
2013	Pinch and exergy based thermosolar integration in a dairy process (Quijera and Labidi, 2013)	Applied Thermal Energy	Case study	Evacuated tube
2014	Integration of industrial solar and gaseous waste heat into heat recovery loops using constant and variable temperature storage (Walmsley et al., 2014)	Energy	Case study	Evacuated tube
2015	Integration options for solar thermal with low temperature industrial heat recovery loops (Walmsley et al., 2015)	Energy	Case study	Evacuated tube
2015	Thermal performance of milk chilling units in remote villages working with the combination of biomass, biogas and solar energies (Edwin and Sekhar, 2015)	Energy	Case study	Evacuated tube
2017	Potential of solar industrial process heating in dairy industry in India and consequent carbon mitigation (Sharma et al., 2017)	Journal of Cleaner Production	Potential	Arun 160 parabolic dish and parabolic trough
2017	Design optimization of a multi-temperature solar thermal heating system for an industrial process (Allouhi et al., 2017)	Applied Energy	Case study	Evacuated tube
2017	Techno-economic analysis of a concentrating solar collector with built-in shell and tube latent heat thermal energy storage (Li et al., 2017)	Energy	Case study	Custom (Fresnel lens and CPC reflector)
2018	Solar energy utilization for milk pasteurization: A comprehensive review (Panchal et al., 2018)	Renewable and Sustainable Energy Reviews	Review	Several
2018	Techno- Economic evaluation of milk chilling unit retrofitted with hybrid renewable energy system in coastal province (Edwin and Sekhar, 2018)	Energy	Case study	Evacuated tube

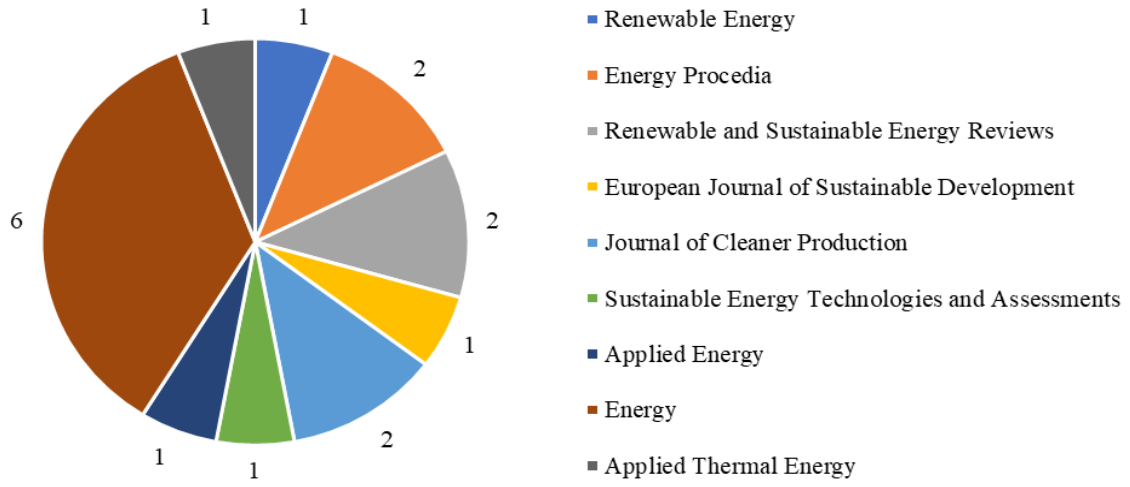

Figure 3. Number of articles per journal

Table 2. Articles selected from Google Scholar.

Year	Title/Author	Journal	Type	Collector
2011	Integration of a solar thermal system in a dairy process (Quijera et al., 2011)	Renewable Energy	Case study	Evacuated tube
2012	Demonstration of three large scale solar process heat applications with different solar thermal collector technologies (Pietruschka et al., 2012)	Energy Procedia	Case study	Parabolic Trough
2013	Application of solar energy for sustainable dairy development (Desai et al., 2013)	European Journal of Sustainable Development	Review	Several
2014	A review on development of solar drying applications (Pirasteh et al., 2014)	Renewable and Sustainable Energy Reviews	Review	Several
2014	Development of an evaluation methodology for the potential of solar-thermal energy use in the food industry (Müller et al., 2014)	Energy Procedia	Potential	
2017	Solar energy for process heating: a case study of select Indian industries (Suresh and Rao, 2017)	Journal of Cleaner Production	Potential	Flat plate and evacuated tube
2018	Financial viability of solar industrial process heating and cost of carbon mitigation: A case of dairy industry in India (Sharma et al., 2018)	Sustainable Energy Technologies and Assessments	Case study	Parabolic trough

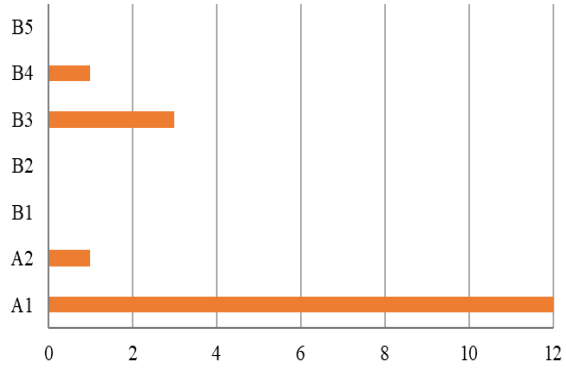

Figure 4. Number of articles per indicative index of quality Qualis.

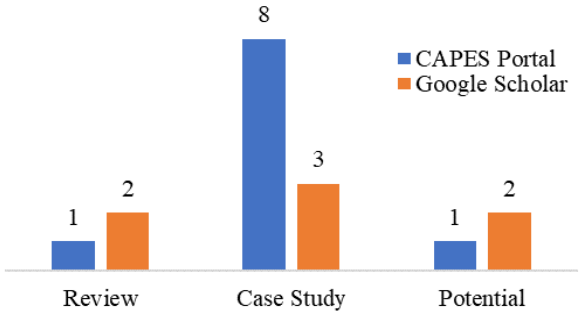

Figure 5. Types of articles per search tools.

With regard to the reviews articles, the work (Pirasteh et al., 2014) review the role of the drying system in industry and agriculture. The authors analyzed the energy consumption capacity and the availability of the required energy for the products to be dried. Economics, environmental, and political aspects of using solar dryers were discussed. Special attention was given to industrial drying, conducting a comprehensive review of the new approach to use solar energy in the drying process.

For milk pasteurisation, dairy industries require boiler or heat exchanger. Sometimes they need fossil fuels to warm the work fluid. The aim of the review paper (Panchal et al., 2018) is to discuss various research works, which have been conducted by researchers on milk pasteurisation using solar heating. In short, the authors concluded than evacuated tube collector is the best solution for solar pasteurisation system, attainings higher temperature quickly. However, this temperature is not obtained with precision, which is desirable. On the other hand, this behaviour is not observed in flat plate collector contrariwise. So the evacuated tube collector is not as good as flat plate collector to control the process temperature.

According to (Müller et al., 2014) the most critical factor to determine the potential of solar thermal energy use is the area available on roofs. In this sense, they developed a methodology to better evaluate different types of roofs. The criteria used were: slope and orientation, shading, amount of continuous area (without obstructions) and the number of

buildings. These factors are scored and, as a result, the authors obtained coefficients that were used in the classification of the areas.

The potential of solar energy use in the Indian dairy industry was evaluated in (Sharma et al., 2017). First, they estimated the thermal load of milk processing and determined the solar insolation. Afterwards, they evaluated the performance of a solar water heating system in different regions of India. Finally, they estimated the potential for reducing greenhouse gases. They predict that 20 to 30% of the thermal demand of the sector can be supplied by solar heating systems without energy storage. As an example, for locations with a DNI of 600 W/m² and exclusive use of oil, they estimate a reduction of 15,000 t in CO_2 emissions.

In (Suresh and Rao, 2017) was analyzed the use of solar energy in some industry sectors. The processes that use this technology, the temperature ranges, the thermal demand, the required collector area, the initial cost and the payback period were identified. For the dairy industry, they estimated the generation of 0.49 PJ of thermal energy, with an area of 0.16 million square meters and an initial cost of US $ 25 million. The use of a solar heating system would be able to reduce 12.9 ktoe from the 64.6 ktoe of oil currently required.

As for the case studies identified, most present studies of the use of solar heating systems with other energy sources (Walmsley, T.G. et al., 2014), (Atkins et al., 2010), (Walmsley, T.G. et al., 2015), (Quijera et al., 2011), (Quijera and Labidi, 2013), (Edwin and Sekhar, 2018) and (Edwin and Sekhar, 2015), i.e. , hybrid systems.

Three hybrid systems are treated in (Pietruschka et al., 2012). One is a dairy company, in which the reduction of gas use can reach 120,000 m³ per year. In this case, the system presents an approximate solar fraction of 41% and an annual reduction of 77.23 tons in the CO_2 emission. Another similar case is presented in (El Mkadmi and Wahed, 2017). The performance of the same solar heating system was evaluated in three different locations. In all three cases, evacuated tube solar collectors were more efficient than flat plate solar collectors. With respect to the energy generated, the system is able to supply 76% to 94% of the processes demand.

Fig. 6 shows processes that are addressed in the selected articles. Pasteurization and drying appearing the most. Both processes do not require high operating temperatures - pasteurization between 60ºC and 80ºC (Farjana et al., 2018) and drying between 40ºC and 60ºC (Sharma et al., 2017). In both cases, flat plate collectors can be used, in which the working fluid can reach temperatures close to 90°C. For pasteurization, evacuated tube collectors can be used, in which the working fluid can reach temperatures close to 120ºC. However, the evacuated tube collector is not as good as flat plate collector to control the process temperature (Panchal et al., 2018).

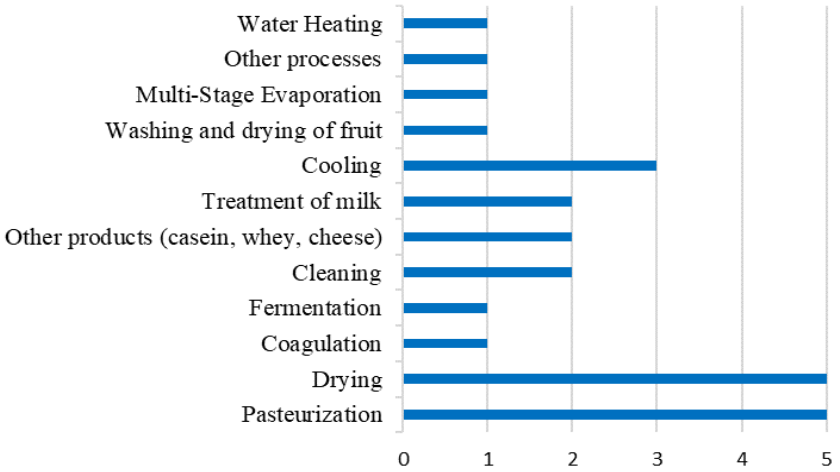

Figure 6. Processes identified in selected articles.

Cascaes (2019) identified sectors with potential for the use of SHIP in Brazil from the analysis of the thermal demands of the main processes of different sectors and the industrial centers geographic location. This allows to relate the average annual solar radiation values available in the Brazilian territory to the industries location.

Fig. 7 shows the annual daily average total solar irradiance in the tilted plane (inclination equals latitude) and the location of the industrial centers with more than ten dairy industries. The annual daily average total solar irradiance received by the southern region of Brazil, Fig.7 - detail, varies between 4,000 W/m^2 and 6,000 W/m^2. This information allows the selection of the collector types that offer a good performance in each region and meets the industries heat demand.

According to Cascaes (2019) the use of stationary collectors for dairy sector is possible in several states, such as São Paulo (SP), Minas Gerais (MG) and Rio Grande do Sul (RS), the southernmost state of Brazil, Fig. 7 - detail. Among stationary solar collectors, the cheapest is the flat plate collector, followed by the evacuated tube collector. Both collectors can be used for incident radiation levels in the southern region of Brazil (Cascaes, 2019). These collectors are

suitable for processes whose water temperature does not exceed 100 ºC, which is the case of pasteurization and washing, for example.

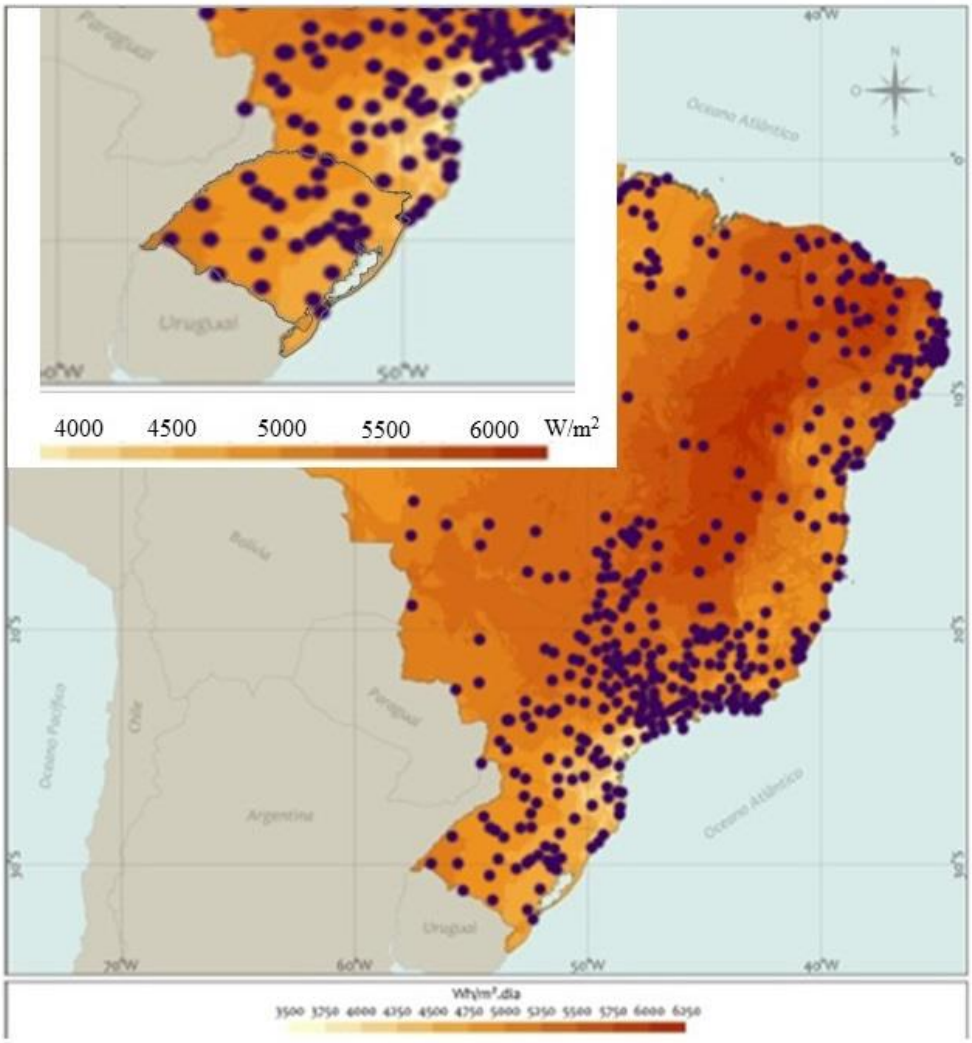

Figure 7. Locations with more than ten industries in the dairy sector on a map that shows the annual daily average total solar irradiance in the tilted plane. (Adapted from Cascaes, 2019)

Combining the results obtained by Cascaes (2019), and the processes identified through the systematic review of the literature, it can be seen that the SHIP for most dairy sector process, Fig. 6, can be applied in the southern region of Brazil. Nevertheless, it is possible to use stationary cheaper collectors, as the flat plate and evacuated tube collectors.

4. CONCLUSIONS

This work aimed to a literature systematic review with bibliometric analysis on industrial heating processes feasible to use solar thermal collectors in dairy sector. The CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) Journal Portal was used. This portal is an electronic resource that allows the application of several filters. This search resulted in only 10 articles on the subject of interest. Then, the electronic portal Google Scholar was used. Its advantage is to provide results from additional sources not covered by traditional portals, such as Science Direct for example. At the end, the search led to a total of 17 articles distributed in 9 journals - 3 reviews articles, 11 case studies and 3 potential analyzes.

The most cited and evaluated processes were pasteurization and drying. Both processes do not require high operating temperatures - pasteurization between 60ºC and 80ºC and drying between 40ºC and 60ºC. In both cases, flat plate collectors and evacuated tube collectors can be used. Furthermore, the annual daily average total solar irradiance received by the southern region of Brazil varies between 4 kW/m^2 and 6 kW/m^2. These irradiance values are sufficient to raise the temperature of the water near the process temperature (below 100 ºC) using the cited collectors.

So, processes and applications with great potential for using solar thermal heating in the dairy sector in the southern region of Brazil are water heating, pasteurization, drying, cleaning and fermentation, for example. All these processes require temperatures below 100 ºC. As a continuation of this work, it is suggested the financial and thermal evaluation of a SHIP system for one of the identified processes.

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